AD-A068 365 COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CT F/G 20/1
ECONOMIC ANALYSIS OF SOLAR PHOTOVOLTAICS FOR LOW-POWER LIGHTED --ETC(U)
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UNCLASSIFIED CGR/DC-11/78 USCG-D-23-79 NL

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Technical Report Documentation Page

1. Report No. (18) USCG-D-23-79 (19)	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle (6)
ECONOMIC ANALYSIS OF SOLAR PHOTOVOLTAICS FOR LOW-POWER LIGHTED AIDS TO NAVIGATION

5. Report Date (11) June 1978

6. Performing Organization Code

7. Author(s) (10)
William R. Allen

8. Performing Organization Report No. (14) CGR&DC-11/78 (12) 53p.

9. Performing Organization Name and Address
United States Coast Guard
Research and Development Center
Avery Point
Groton, Connecticut 06340

10. Work Unit No. (TRAIS)
2705.1

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, DC 20590

13. Type of Report and Period Covered (9)
Final Report,

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A detailed economic analysis with decision-making criteria for converting the present energy storage system used on U.S. Coast Guard low-power lighted aids to navigation to one that relies upon conversion of solar energy by photovoltaics is presented. The analysis demonstrates that converting 12-volt lighted aids to navigation from reliance on primary air-cell batteries to reliance on solar photovoltaics is attractive from an economic point of view. However, questions concerning reliability and life must be answered before the Coast Guard plans conversion to solar photovoltaics.

17. Key Words	18. Distribution Statement
solar power, photovoltaics, economic analysis	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	47	

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is not authorized

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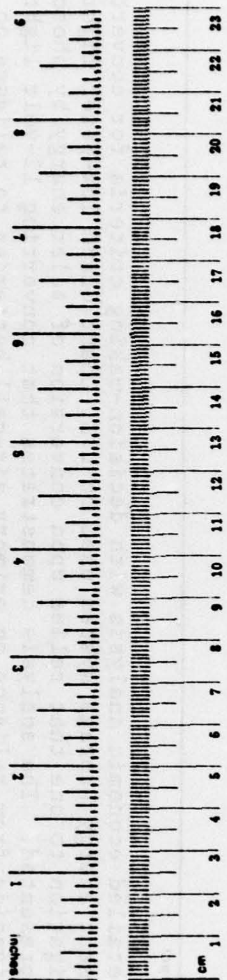
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

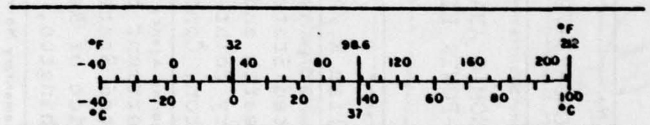
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

Over 14,000 lighted aids to navigation are maintained by the United States Coast Guard. The vast majority of these are powered by primary batteries of the zinc-carbon air-depolarized type.

Rising battery costs and environmental concerns in disposal of spent batteries prompted the Coast Guard to initiate several research thrusts in alternative low-power energy sources for aids to navigation. Research focused on wind- and wave-activated generators, fuel cells, and solar photovoltaic energy systems. Of these, the solar photovoltaic system held the most promise for widespread usage.

About five years of research effort has established the technical feasibility of using solar energy photovoltaics in both lighted buoys and lighted fixed aids, and the problems associated with these applications are being thoroughly investigated.(1) Both laboratory and field testing have been performed, and several research efforts continue. Fifty lighted aids have been converted to use solar photovoltaic energy in the Seventh Coast Guard District (Miami area) as a feasibility demonstration.

The purpose of this report is to provide the economic analysis and develop other decision-making criteria for converting the present energy storage system to one that relies upon conversion of solar energy by photovoltaics as the primary means of providing electricity to power lighted aids to navigation.

1.1 Background

1.1.1 Solar Photovoltaic Cells

Although the photovoltaic effect, i.e., the direct conversion of light into electricity, was first noticed by scientists about 100 years ago, the first practical use of this phenomenon did not come until the United States space program used silicon cells to convert sunlight to electrical energy for powering a radio transmitter in its first permanent satellite in the late 1950's. Silicon continues to be used almost exclusively today in commercially available solar photovoltaic cells.

Basically, a photovoltaic cell is a large area semiconductor diode, constructed such that photons can penetrate into the region of the diode p-n junction. A p-n junction can be formed close to one surface of the semiconductor by allowing boron to diffuse into the surface of an n-type single crystal wafer at high temperatures. The p-n junction formed between the n-type silicon wafer and the p-type surface layer provides the electric field which gives rise to the diode characteristics as well as the photovoltaic effect.

Each cell can supply current at voltages up to one-half volt. At lower voltages the current supplied is nearly independent of voltage, but varies with irradiance. About 30 milliamps of current can be obtained from each square centimeter surface exposed to bright sunlight. The maximum power

deliverable to an external load is typically 11 to 12 percent of the total solar energy incident on the cell, although over 15 percent has been demonstrated in laboratory models. To obtain higher voltages, cells are connected in series while higher currents are obtained by connecting cells in parallel. Such connections are made when cells are packaged in modules, which then become the building blocks for solar arrays designed to meet specific needs.

1.1.2 Photovoltaic Generator Systems

Virtually all photovoltaic generator systems in use today employ rechargeable electric storage batteries to provide a steady source of power and to act as a buffer between the photovoltaic cell array and the load.

In addition to a properly sized photovoltaic cell array and storage battery, a complete solar electric generator system for powering lighted aids to navigation will include a blocking diode and voltage regulator. The blocking diode prevents current drain from the battery through the photovoltaic cell array at night. The voltage regulator prevents overcharging the battery. A schematic for a complete system is shown in Figure 1-1.

1.2 Primary Batteries

1.2.1 Historical Perspective

About 1910 acetylene gas lights for buoys were brought into general usage. Battery-powered lights started being used about 1935 but it was 1968 before the last acetylene-lighted aid in the U.S. was retired. Large secondary (rechargeable) lead-acid storage batteries were used, requiring removal to shore depots for periodic recharging and redeployment. In 1962, the shift from secondary batteries to primary (non-rechargeable) batteries began with the principal economic justifications being the elimination of battery charging shops at shore depots and reduced handling problems.

1.2.2 Current Perspective

The life span for zinc-air primary batteries varies due to many factors, but on the average, it is about two years, being limited to three years due to shelf-life considerations.

Besides its basic non-biodegradability, a depleted zinc-air primary battery has certain components that can have detrimental effects on the marine environment. These batteries contain a highly alkaline solution of pH 14. They also contain mercury, a long-term pollutant, which is present in the zinc anodes and the byproduct residue. Accordingly, primary batteries cannot be disposed of on-site nor can they be disposed of by deep ocean dumping. Depleted batteries must be returned to shore depots for subsequent shore site disposal.(2)

Based on a survey of all Coast Guard districts conducted during May and June 1977, it is evident that disposal costs now are low and

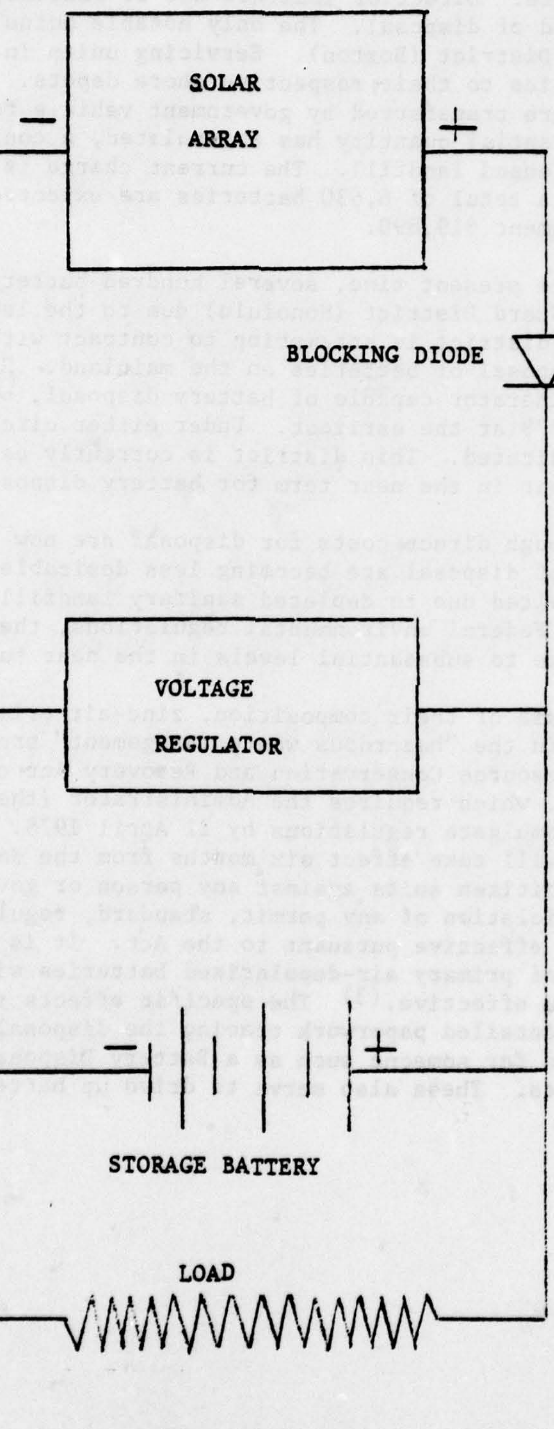

Figure 1-1

Electrical Schematic of a Solar-Powered Photovoltaic Generator System

not readily identifiable. Direct or indirect use of sanitary landfill is the most widely used method of disposal. The only notable actual costs occur in the First Coast Guard District (Boston). Servicing units in this district return depleted batteries to their respective shore depots. From each of these, the batteries are transferred by government vehicle to Base Boston and stored. After a substantial quantity has accumulated, a contractor transports the batteries to a licensed landfill. The current charge is $3 per battery. For fiscal year 1978, a total of 6,630 batteries are expected to be disposed of, costing the government $19,890.

At the present time, several hundred batteries are stored in the Fourteenth Coast Guard District (Honolulu) due to the lack of adequate disposal areas. This district is attempting to contract with the State of California for the disposal of batteries on the mainland. Hawaii has initiated a contract for an incinerator capable of battery disposal, but completion is not scheduled until 1978 at the earliest. Under either circumstances, substantial costs are indicated. This district is currently estimating recurring costs of $8,000 per year in the near term for battery disposal.

Although direct costs for disposal are now low, it is obvious that present methods of disposal are becoming less desirable. Indeed, if present methods are halted due to depleted sanitary landfills or more restrictive local, state, or Federal environmental regulations, the direct cost to the government may rise to substantial levels in the near future.

Because of their composition, zinc-air primary batteries will undoubtedly come within the "hazardous waste management" provisions of the regulations of the "Resource Conservation and Recovery Act of 1976," Public Law 94-580 (90 STAT 2795), which requires the Administrator (the Environmental Protection Agency) to promulgate regulations by 21 April 1978. The Act specifies that the regulations will take effect six months from the date they are promulgated and authorizes citizen suits against any person or government agency who is alleged to be in violation of any permit, standard, regulation, or requirement which has become effective pursuant to the Act. It is anticipated that the cost of disposal of primary air-depolarized batteries will increase when the regulations become effective.[3] The specific effects resulting from this Act are unknown, but detailed paperwork tracing the disposal of individual batteries and the need for someone such as a Battery Disposal Manager are two highly probable effects. These also serve to drive up battery disposal cost.

2.0 SYSTEM DESIGN FOR ECONOMIC ANALYSIS

A wide variety of factors must be considered in the design of solar photovoltaic energy systems for low-power lighted aids to navigation. A representative listing of such factors would include lamp current, duty cycle, illumination control, load voltage, battery life, mission duration, energy demand, solar insolation variations, weather conditions, ocean states, ultraviolet radiation, physical impact to the structure, guano, and buoy motion.(4) A computer program to handle those factors relating to the size of the system (i.e., solar insolation, load, etc.) has been developed for the Coast Guard by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. Although the contract was complete as of the writing of this report, the program was not available for use in connection with this concurrent analysis.

To accomplish needed systems design for the purposes of this economic analysis, it was necessary to use the simplified computer program developed by the Coast Guard Research and Development (R&D) Center. Although simplified relative to the JPL version, this Design Integration Model yields a design having a good match to actual systems in operation.(5) This program uses average monthly insolation, a straight photovoltaic efficiency, a complex battery charge efficiency, and a load based on average hours of darkness.

For each Coast Guard district, a district-wide design was established varying as a function of nominal lamp current and lamp duty cycle. (Duty cycle and flash characteristics are directly related; see Table 2-1.) For a given district, insolation data were taken from the Climatic Atlas of the United States(6) using a representative location, and hours of darkness between sunset and sunrise were calculated from the Nautical Almanac(7) using an assumed latitude. (See Table 2-2.) These inputs varied as a function of the general geographic location of the districts. Constant input assumptions used were a 100 percent of the initial battery capacity and a 90 percent of the initial solar array efficiency. The 10 percent differential in solar efficiency accounts for degradation over the life of the solar array due to such things as dirt buildup, ultraviolet radiation effects, and aging. The maximum permitted depth of discharge on the battery is taken as 50 percent. This is to keep the battery voltage above 12.0V in any location in an average year and to keep the system from failing in a low insolation year or from freezing in an extremely cold year.

Given the above, a standard "power package," consisting of an 8-watt (peak power) solar photovoltaic module coupled with a 100 ampere-hour (Ah) battery, was used as a standardized design. Although solar photovoltaic modules are available in any power increment, for the purposes of this report the 8-watt (50-mm round cells, 36 in series) array is assumed since this is the smallest size that is readily available. A 100 Ah battery works well with this size module. Working well means that if the battery reaches its design minimum of 50 percent capacity, it will experience about six months at less than full charge and six months at full charge. Since the battery spends a long time in a partially discharged condition, a considerable period of time at full charge may be necessary to restore capacity. A system with any other module size would require a battery of proportional size to meet these design

TABLE 2-1

DUTY CYCLE RELATED TO FLASH CHARACTERISTIC

FLASH CHARACTERISTIC	DUTY CYCLE
FL6 (.6)	10 Percent
FL4 (.4)	10 Percent
FL2.5 (.3)	12 Percent
GPFL5 (2X.4)	16 Percent
FL6 (1.0) (obsolete)	16.7 Percent
IQKFL (6X.3)	18 Percent
FL2.5 (.5) (obsolete)	20 Percent
FL4 (1.0) (obsolete)	25 Percent
MO(A) (.4, 2.0)	30 Percent
QKFL (0.3)	30 Percent
GPFL6 (2X1.0)	33 Percent
EI (3.0)	50 Percent
OCC4 (3.0)	75 Percent

NOTE: From Enclosure (2) to COMDTINST 10500.32A of 1 August 1973

TABLE 2-2

ASSUMPTIONS FOR DESIGN INTEGRATION MODEL

COAST GUARD DISTRICT	REPRESENTATIVE INSOLATION DATA LOCATION	REPRESENTATIVE LATITUDE FOR HOURS OF DARKNESS	YEARS OF RECORD
1	Boston, Massachusetts	40°N	16
2	University of Missouri	40°N	6
3	Newport, Rhode Island*	40°N	24
5	Washington (Silver Hill), DC	40°N	7
7	Tampa, Florida	30°N	9
8	Appalachicola, Florida	30°N	10
9	Put-In-Bay, Ohio	45°N	11
11	Los Angeles (WBO), California	35°N	9
12	Medford, Oregon	40°N	11
13	Astoria, Oregon	45°N	8
14	Pearl Harbor, Hawaii	20°N	5
17	Annette, Alaska	56°N	7

* Newport, Rhode Island, although in the First CG District, was considered sufficiently representative Third CG District to be used instead of an actual Third CG District location.

criteria. For example, if a 1-watt module and 12 Ah batteries were used as a "package" in the First Coast Guard District, the total energy required would only be 13 percent less than with the 8-watt/100 Ah "package," but the cost per watt or per amp-hour would increase as would the complexity of each system.

The only alteration to the above assumption was the inclusion into the overall system design of a "one-half" power package, i.e., a 4-watt solar photovoltaic module (half 50 mm diameter cells, 36 in series) coupled with a 100 Ah battery. This was done to better approximate energy requirements for aids in geographic locations having a large amount of sunlight (i.e., high insolation) or for aids having low lamp ratings and light duty cycles. This results in a slightly better match between cost and energy requirements.

There is a practical limit to the size and weight of a solar array that can be installed on aids. This will be assumed to be four 8-watt modules for buoys and eight 8-watt modules for fixed aids. Otherwise, the solar photovoltaic array would be excessively large and cumbersome for suitable installation. It is assumed that the preferred approach to conversion to solar energy would be a total conversion; it will also be assumed that any aids having energy requirements greater than the four and eight 8-watt modules previously mentioned will be downgraded as to lamp rating and/or duty cycle to permit the four and eight module maximums. This could be accomplished also by converting fixed aids to commercial power or by replacing buoys with fixed aids.

At this point, the Design Integration Model computer program was run for each location shown in Table 2-2, using the previously mentioned assumptions. Sensitivity analyses were performed to determine the maximum load which would yield a depth of discharge for the battery of no more than 50 percent. An example of a program output considered acceptable is shown in Table 2-3. Starting with this design point, the number of power packages required for each combination of lamp rating and duty cycle was determined for each district. The results are shown in Table 2-4.

This completes the assumed system design for economic analysis purposes.

TABLE 2-3
EXAMPLE OF DESIGN INTEGRATION MODEL OUTPUT

CGDNINE PUT-IN-BAY, OH 45N — FLASH CHAR-FL4(.4)
ARRAY PWR @ 14VOLTS= 8.0 WATTS — ARRAY DEG = 10%
BATTERY CAPACITY= 100 Ah — LAMP SIZE = 0.55 Amp

MONTH	LANGLEYS	HRS DARK	ARRAY OUT AH	LOAD AH	BATTERY CAP PERCENT
JUL 01-15	8415	129	50	11	100.0
JUL 16-30	8415	129	50	11	100.0
AUG 01-15	7305	149	44	13	100.0
AUG 16-30	7305	149	44	13	100.0
SEP 01-15	5730	171	34	14	99.7
SEP 16-30	5730	171	34	14	100.0
OCT 01-15	4125	195	25	16	99.8
OCT 16-30	4125	195	25	16	99.8
NOV 01-15	2160	218	13	18	92.1
NOV 16-30	2160	218	13	18	85.4
DEC 01-15	1635	228	10	19	75.4
DEC 16-30	1635	228	10	19	65.6
JAN 01-15	1890	224	11	18	57.8
JAN 16-30	1890	224	11	18	50.2
FEB 01-15	3060	203	18	17	50.8
FEB 16-30	3060	203	18	17	51.5
MAR 01-15	4530	182	27	15	62.0
MAR 16-30	4530	182	27	15	72.1
APR 01-15	5790	156	35	13	90.1
APR 16-30	5790	156	35	13	99.8
MAY 01-15	7020	138	42	12	100.0
MAY 16-30	7020	138	42	12	100.0
JUN 01-15	8160	126	49	11	100.0
JUN 16-30	8160	126	49	11	100.0

Insolation data is from Climatic Atlas of the United States.

Langley is the unit used to denote one gram-calorie per square centimeter.

TABLE 2-4

NUMBER OF POWER PACKAGES REQUIRED FOR EACH LAMP RATING AND DUTY CYCLE COMBINATION

FIRST DISTRICT

NOMINAL LAMP RATING (AMPS)	DUTY CYCLE (percent)							
	.1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1	1	1	2	2	2	3
.55	2	2	2	2	3	3	4	6
.77	2	2	3	3	4	4	5	8
1.15	2	3	3	4	6	6	8	11
2.03	4	5	6	7	9	9	13	19
3.05	6	7	8	10	16	16	20	29

SECOND DISTRICT

NOMINAL LAMP RATING (AMPS)	DUTY CYCLE (percent)							
	.1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1/2	1	1	2	2	2	3
.55	1	2	2	2	3	3	4	5
.77	2	2	2	2	4	3	5	7
1.15	2	2	3	3	5	5	7	9
2.03	3	4	5	6	9	9	10	16
3.05	5	6	7	8	12	12	17	25

TABLE 2-4

NUMBER OF POWER PACKAGES REQUIRED FOR EACH LAMP RATING AND DUTY CYCLE COMBINATION

THIRD DISTRICT

NOMINAL LAMP RATING (AMPS)	DUTY CYCLE (percent) .1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1/2	1	1	2	2	2	3
.55	1	2	2	2	3	3	4	5
.77	2	2	2	3	4	4	5	7
1.15	2	3	3	3	5	5	7	10
2.03	3	4	5	6	9	9	12	17
3.05	5	6	8	9	14	14	18	26

FIFTH DISTRICT

NOMINAL LAMP RATING (AMPS)	DUTY CYCLE (percent) .1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1/2	1	1	2	2	2	3
.55	1	1	2	2	3	3	3	5
.77	2	2	2	2	3	3	5	6
1.15	2	2	3	3	5	5	7	9
2.03	3	4	5	5	8	8	11	16
3.05	5	6	7	8	13	13	16	24

TABLE 2-4

NUMBER OF POWER PACKAGES REQUIRED FOR EACH LAMP RATING AND DUTY CYCLE COMBINATION

SEVENTH DISTRICT — DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)	.1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1/2	1/2	1/2	1	1	1	2
.55	1/2	1	1	1	2	2	2	3
.77	1	1	2	2	2	2	3	4
1.15	1	2	2	2	3	3	4	6
2.03	2	3	3	4	5	5	7	10
3.05	3	4	4	5	8	8	10	15

EIGHTH DISTRICT — DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)	.1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1/2	1/2	1/2	1	1	1	2
.55	1/2	1	1	1	2	2	2	3
.77	1	1	2	2	2	2	3	4
1.15	2	2	2	2	3	3	4	6
2.03	2	3	3	4	6	6	7	11
3.05	3	4	5	5	9	9	11	16

TABLE 2-4

NUMBER OF POWER PACKAGES REQUIRED FOR EACH LAMP RATING
AND DUTY CYCLE COMBINATION

NINTH DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)	.1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1	1	1	2	2	2	3
.55	2	2	2	2	3	3	4	6
.77	2	2	3	3	4	4	6	8
1.15	2	3	3	4	6	6	8	12
2.03	4	5	6	7	9	9	13	20
3.05	6	7	9	10	16	15	20	30

ELEVENTH DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)	.1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1/2	1/2	1/2	1	1	2	2
.55	1	1	1	2	2	2	3	4
.77	1	2	2	2	3	3	4	5
1.15	2	2	2	3	4	4	5	7
2.03	3	3	4	4	6	6	8	12
3.05	4	4	5	6	10	10	13	19

TABLE 2-4

NUMBER OF POWER PACKAGES REQUIRED FOR EACH LAMP RATING
AND DUTY CYCLE COMBINATION

TWELFTH DISTRICT

NOMINAL LAMP RATING (AMPS)	DUTY CYCLE (percent) .1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1	1	1	2	2	2	3
.55	2	2	2	2	3	3	4	6
.77	2	2	3	3	4	4	6	8
1.15	2	3	4	4	6	6	8	11
2.03	4	5	6	7	9	9	14	20
3.05	6	7	9	10	16	16	20	30

THIRTEENTH DISTRICT

NOMINAL LAMP RATING (AMPS)	DUTY CYCLE (percent) .1	.12	.16	.18	.30	.33	.50	.75
.25	1	1	1	2	2	2	3	4
.55	2	2	2	3	4	4	5	7
.77	2	2	3	3	5	5	6	9
1.15	3	3	4	5	7	7	9	14
2.03	5	5	7	8	12	12	16	24
3.05	7	8	10	13	19	19	24	36

TABLE 2-4

NUMBER OF POWER PACKAGES REQUIRED FOR EACH LAMP RATING
AND DUTY CYCLE COMBINATION

FOURTEENTH DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)	.1	.12	.16	.18	.30	.33	.50	.75
.25	1/2	1/2	1/2	1/2	1/2	1	1	2
.55	1/2	1/2	1	1	2	2	2	3
.77	1	1	1	2	2	2	3	4
1.15	1	2	2	2	3	3	4	5
2.03	2	2	3	3	5	5	6	9
3.05	3	3	4	5	7	7	9	14

SEVENTEENTH DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)	.1	.12	.16	.18	.30	.33	.50	.75
.25	2	2	2	2	3	3	4	5
.55	2	3	3	4	5	5	7	10
.77	3	3	4	5	7	7	9	14
1.15	4	5	6	7	10	10	14	20
2.03	7	8	10	11	18	18	23	35
3.05	10	12	15	17	28	28	35	53

3.0 SYSTEM COST DEVELOPMENT

Since the cost to convert a given lighted aid is heavily dependent upon the power required and somewhat dependent upon whether it is a buoy or fixed aid, an inventory of all 12-volt lighted aids was run from the SANDS (Simplified Aids to Navigation Data System) data bank. This inventory (dated 1 July 1977) reflected the count by district of all lighted aids by lamp rating and flash characteristic (and hence duty cycle) and indicated whether it was a buoy or fixed aid. Since the code numbers did not clearly reflect flash characteristic in all cases, it was necessary to make some assumptions to render the inventory compatible with the standard flash characteristics shown in Table 2-1. Consultation with the Minor Aid Systems Section, Signal Branch, of the Ocean Engineering Division of the Office of Engineering at Coast Guard Headquarters and the R&D Center established the assumptions used. These are reflected in Table 3-1. Since there are still a sizeable number of 6-volt systems in operation in the Second District, the nominal lamp ratings of 0.46 and 0.92 amps in these systems were assumed to be equivalent to 0.25 and 0.55 amps, respectively, in a 12-volt system. These assumptions permitted a tally of aids by district split out by lamp rating, duty cycle, and type. This tally is shown in Table 3-2.

Once this was accomplished, it was possible to determine the number of lighted buoys and fixed aids associated with the number of required power packages. These numbers are shown in Table 3-3.

From the numbers generated in Table 3-3, it is possible to calculate the approximate percentage of the total population included in the design being used in this report. The SANDS inventory of 1 July 1977 indicated a total number of 14,232 12-volt aids throughout the Coast Guard. If the 209 aids purposely excluded because they exhibited a fixed characteristic (and thus were powered commercially from shore) are deducted, 99.9 percent of the remaining aids can be powered within the assumed design.

3.1 Development of Project Cost Estimates

Consultation with those working on the Energy Sources Project in the Physics Branch of the R&D Center and with the Ocean Engineering Division of the Office of Engineering at Coast Guard Headquarters, along with independent judgment, established an estimated cost range for each component required to convert a buoy or fixed aid to a solar photovoltaic power system. Since each item could vary in cost, lowest estimated cost and highest estimated cost figures were developed on the assumption that actual cost would most likely be somewhere within the cost range established.

The total numbers of the various power package components were derived as a function of the power package requirements developed previously in this report. These are shown in Table 3-4. For the power package components, the following cost estimates were used:

TABLE 3-1

DUTY CYCLE ASSOCIATED WITH THE SANDS CODE FOR FLASH CHARACTERISTIC

SANDS CODE FOR FLASH CHARACTERISTIC	ACTUAL OR ASSUMED DUTY CYCLE	SANDS CODE FOR FLASH CHARACTERISTIC	ACTUAL OR ASSUMED DUTY CYCLE
101	30 Percent	404	10 Percent
103	30 Percent	410	30 Percent
121	18 Percent	430	75 Percent
122	18 Percent	450	16 Percent
145	30 Percent	500s (all)	10 Percent
146	30 Percent	6--*	10 Percent
166	30 Percent	600	10 Percent
178	16 Percent	602	10 Percent
191	33 Percent	606	10 Percent
200	10 Percent	610**	16 Percent
202	10 Percent	620	30 Percent
203	10 Percent	630	50 Percent
205	10 Percent	634	50 Percent
250	12 Percent	776	16 Percent
253	12 Percent	791	33 Percent
255	18 Percent	848	18 Percent
310	33 Percent	881	30 Percent
315	50 Percent	900s (all)	10 Percent
400	10 Percent		

* Code numbers other than those shown above were considered in error and thus were not used. Only a few code numbers are involved. The 6-- code number shown above appears that way in the SANDS printout used.

** Obsolete.

TABLE 3-2

NUMBER OF AIDS BY TYPE COMPATIBLE WITH ECONOMIC ANALYSIS DESIGN

FIRST DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	1				2			
	S	-				1			
.55	B	9	1		2				
	S	20	-		-				
.77	B	131	18		6	17			
	S	30	4		-	2			
1.15	B	123	13	1	15	53		-	
	S	29	2	3	1	4		1	
2.03	B	1	-	-	-	1		-	
	S	15	3	4	2	-		1	
3.05	B	-				-			
	S	2				3			

B = Buoys S = Structures

SECOND DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	42		2	6	9	-		
	S	1413		132	2	81	95		
.55	B	6		1		3	-		
	S	493		-		11	4		
.77	B	-							
	S	3							
1.15	B	-							
	S	1							
2.03	B	-							
	S	3							
3.05	B								
	S								

B = Buoys S = Structures

TABLE 3-2

NUMBER OF AIDS BY TYPE COMPATIBLE WITH ECONOMIC ANALYSIS DESIGN

THIRD DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	-				-		-	
	S	9				4		1	
.55	B	159	25		32	63		-	-
	S	163	3		1	9		6	2
.77	B	172	45	-	19	26		-	-
	S	73	10	1	4	5		5	1
1.15	B	311	21		5	26		-	
	S	142	5		6	4		5	
2.03	B	2	1		-	-		-	-
	S	13	-		2	1		2	1
3.05	B	-						-	
	S	1						1	

B = Buoys S = Structures

FIFTH DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	-	1			-		-	
	S	1	2			26		21	
.55	B	101	18		10	26		-	
	S	1073	191		36	163		5	
.77	B	206	24		5	66		-	
	S	27	15		2	10		4	
1.15	B	49	11	-	3	15	-	-	
	S	25	9	1	1	9	1	1	
2.03	B	5	1		-	-			
	S	15	-		2	1			
3.05	B	-		-					
	S	14		1					

B = Buoys S = Structures

TABLE 3-2

NUMBER OF AIDS BY TYPE COMPATIBLE WITH ECONOMIC ANALYSIS DESIGN

SEVENTH DISTRICT — DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	2	2		-	11		-	
	S	3	1		2	31		2	
.55	B	262	32		6	51		-	
	S	1250	39		7	137		135	
.77	B	42	7	1	2	13		-	
	S	6	1	-	-	10		8	
1.15	B	26	-	-	1	5		-	-
	S	22	3	1	2	18		9	2
2.03	B	1	-	-		1	-	-	
	S	15	1	1		5	1	1	
3.05	B	-						-	
	S	2						1	

B = Buoys S = Structures

EIGHTH DISTRICT — DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	-	-			2			
	S	1	1			-			
.55	B	29	15		4	15		-	-
	S	755	117		12	193		70	6
.77	B	132	54		2	49		1	-
	S	53	44		2	55		48	4
1.15	B	35	12			26		-	-
	S	34	9			15		30	1
2.03	B	1	1		-	2		-	
	S	6	7		1	8		58	
3.05	B	-							-
	S	4							1

B = Buoys S = Structures

TABLE 3-2

NUMBER OF AIDS BY TYPE COMPATIBLE WITH ECONOMIC ANALYSIS DESIGN

NINTH DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	1	-			-			
	S	1	-			3			
.55	B	148	27		5	38		-	
	S	83	27		4	9		9	
.77	B	249	16	-	12	22		-	
	S	48	13	2	-	3		3	
1.15	B	15	12	1	-	5		-	
	S	33	5	2	4	3		6	
2.03	B	-	-			2		-	-
	S	26	6			3		1	2
3.05	B	-	-	-		-		-	-
	S	12	1	2		2		2	2

B = Buoys S = Structures

ELEVENTH DISTRICT

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B								
	S								
.55	B		-						
	S		1						
.77	B	10	6			2			
	S	-	-			-			
1.15	B	33	5	-		15		-	
	S	14	6	1		-		1	
2.03	B	-	-		-				
	S	8	2		1				
3.05	B								
	S								

B = Buoys S = Structures

TABLE 3-2

NUMBER OF AIDS BY TYPE COMPATIBLE WITH ECONOMIC ANALYSIS DESIGN

TWELFTH DISTRICT — DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	-	1			-		-	
	S	28	15			25		14	
.55	B	22	2		2	7		1	
	S	234	18		1	15		4	
.77	B	2				-		-	
	S	-				2		1	
1.15	B	46	3		3	13		2	
	S	9	2		-	-		1	
2.03	B	-							
	S	2							
3.05	B								
	S								

B = Buoys S = Structures

THIRTEENTH DISTRICT — DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B		-						
	S		-						
.55	B	19	6		1	4		1	-
	S	510	56		6	127		87	1
.77	B	46	13		5	11		1	
	S	53	7		-	14		10	
1.15	B	91	3		11	40		-	-
	S	41	-		2	15		13	1
2.03	B	-	-			-		-	
	S	5	-			9		6	
3.05	B								
	S								

B = Buoys S = Structures

TABLE 3-2

NUMBER OF AIDS BY TYPE COMPATIBLE WITH ECONOMIC ANALYSIS DESIGN

<u>FOURTEENTH DISTRICT</u>

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	-	-		4	-		-	-
	S	4	7		2	6		4	1
.55	B	31	5		1	10			
	S	17	4		-	1			
.77	B	4	1	-		4			
	S	3	-	1		1			
1.15	B	11	2			3		1	
	S	10	5			-		1	
2.03	B	-				-			
	S	8				1			
3.05	B	-	-		-				-
	S	3	1		2				1

B = Buoys S = Structures

<u>SEVENTEENTH DISTRICT</u>

DUTY CYCLE (percent)

NOMINAL LAMP RATING (AMPS)		.1	.12	.16	.18	.30	.33	.50	.75
.25	B	1	-		1	-		-	
	S	5	2		-	3		1	
.55	B	42	12		2	3		-	
	S	119	45		1	14		5	
.77	B	35	16	3	10	5		-	
	S	179	27	1	1	5		2	
1.15	B	14	1	2	3	2		-	
	S	61	10	1	-	4		1	
2.03	B	-	-	-					
	S	16	2	1					
3.05	B	1							
	S	4							

B = Buoys S = Structures

TABLE 3-3

NUMBER OF BUOYS AND FIXED AIDS ASSOCIATED WITH POWER REQUIREMENTS

Power Packages Required	District 1	2	3	5	7	8	9	11	12	13	14	17	Total
FOR BUOYS													
1/2	1	42	0	1	266	29	1	0	0	0	40	0	380
1	0	14	159	119	124	207	0	10	1	0	17	0	651
2	286	10	585	305	69	114	460	44	74	84	16	44	2091
3	20	3	110	100	5	28	63	2	10	100	3	73	507
4	33	0	27	1	0	0	22	15	4	4	1	19	126
>4	54	0	26	15	1	2	7	0	15	64	0	27	211
										BUOYS SUBTOTAL			3976
FOR FIXED AIDS													
1/2	0	1413	9	3	1256	757	1	0	28	0	40	0	3506
1	0	627	163	1264	108	226	0	1	15	0	18	0	2427
2	84	180	235	161	303	369	211	21	301	626	16	126	2633
3	5	18	37	195	30	80	18	10	17	47	4	254	715
4	18	0	11	0	9	35	42	1	8	127	1	64	316
5	3	0	12	30	6	0	6	1	0	108	3	25	194
6	10	0	2	0	2	9	18	0	1	10	0	1	53
7	2	0	6	2	1	58	1	0	0	16	0	26	112
8	1	0	0	1	0	0	6	0	1	0	0	2	11
>8	4	0	5	0	1	1	14	0	0	29	1	12	67
									FIXED AIDS SUBTOTAL				10030
						GRAND TOTAL (BUOYS AND FIXED AIDS)							14006

TABLE 3-4

TOTAL QUANTITY OF POWER PACKAGE COMPONENTS
REQUIRED FOR SYSTEM OPERATION

Power Package	No. of Aids	No. of 100AH Battery Units	No.of Zener Diodes	No. of Blocking Diodes	No. of Watts
BUOYS					
1/2	380	380	380	-	1520
1	651	651	651	-	5280
2	2091	4182	4182	4182	33456
3	507	1521	1521	1521	12168
4	126	504	504	504	4032
>4	211	844	844	844	6752
SUBTOTAL	3976	8082	8082	7051	63136
FIXED AIDS					
1/2	3507	3507	3507	-	14028
1	2422	2422	2422	-	19376
2	2633	5266	5266	5266	42128
3	715	2145	2145	2145	17160
4	316	1264	1264	1264	10112
5	194	970	970	970	7760
6	53	318	318	318	2544
7	112	784	784	784	6272
8	11	88	88	88	704
>8	67	536	536	536	4288
SUBTOTAL	10030	17300	17300	11371	124368
SYSTEM TOTAL	14006	25382	25382	18422	187504

COMPONENT	LOW ESTIMATE	HIGH ESTIMATE
Batteries	$0.95/Ah	$ 1.60/Ah
Solar photovoltaic arrays	$5.00/watt	$38.00/watt
Zener diodes	$5.00/each	$25.00/each
Blocking diodes	$1.00/each	$ 5.00/each

Cost estimates for converting both buoys and fixed aids, excluding the power package components, were also derived and are shown in Table 3-5. These in turn were extended as a function of the power package requirements and are summarized as shown in Table 3-6.

All low and high cost estimates were then extended relative to the number of aids associated with the power package requirements as shown in Table 3-7, yielding the total estimated low and high conversion costs shown. The low estimate can be construed as a "best of the best" situation, while the high estimate can be interpreted as a "worst of the worst" situation. Of course, this is predicated on the assumptions and system design set forth in this report.

Other project costs besides system conversion also need to be addressed, in particular, initial inventories of power package components, necessary training, and the possibility of needed battery chargers. These are discussed in turn as follows:

(1) Initial Inventory - An initial inventory of 10 percent of the value of the power package components will be assumed under both the low and high estimates.

(2) Training - Conversion to solar energy would require the training of nine 2-man district training teams for one week each (in the estimation of the Aids to Navigation School at Governors Island, New York). According to Commandant (G-PTE), this converts into a $7,100 expense for travel and per diem. This estimate will be assumed under both the low and high estimates. Cost of training the Aids to Navigation School instructor and additional cost, if any, associated with training teams training field personnel, are not included.

(3) Battery Chargers - Under the conditions of operation for the batteries expected by R&D Center investigators, charging of batteries has not been identified as required. The assumption is that the batteries will last for the duration of the buoy relief cycle. Therefore, for the low estimate, a value of zero is assumed. However, according to a report prepared for R&D Center by the U.S. Navy Weapons Quality Engineering Center, Crane, Indiana, there is a possibility that charge retaining batteries would have to be reconditioned periodically to counter sulfation effects and to insure cell voltage balance.[8] An estimate

TABLE 3-5

COST ESTIMATES FOR CONVERSION OF BUOYS AND FIXED AIDS
(EXCLUDING POWER PACKAGE COMPONENTS)

	Estimated Cost Low	Estimated Cost High
BUOYS		
Conversion for one-half and single power packages		
Solar photovoltiac array mounting assembly	$ 25	$ 50
Installation-labor (@ $25/MH: 1MH, 4MH)	25	100
Battery support framing	15	50
	$ 65	$200
Additional conversion cost for each additional power package		
Larger solar photovoltiac array mounting assembly	$ 10	$ 15
More complicated battery support framing	0	10
	$ 10	$ 25
FIXED AIDS		
Conversion for one-half and single power packages		
Solar photovoltiac array mounting assembly	$ 15	$ 40
Installation-labor (1MH @ $25/MH)	25	25
	$ 40	$ 65
Addition conversion cost for each additional power package		
Larger solar photovoltaic array mounting assembly	$ 10	$ 15

TABLE 3-6

SUMMARY OF COST ESTIMATES FOR CONVERSION OF BUOYS AND FIXED AIDS
(EXCLUDING POWER PACKAGE COMPONENTS)

Power Packages Required	BUOYS Low Estimate	BUOYS High Estimate	FIXED AIDS Low Estimate	FIXED AIDS High Estimate
1/2	$ 65	$200	$ 40	$ 65
1	$ 65	$200	$ 40	$ 65
2	$ 75	$225	$ 50	$ 80
3	$ 85	$250	$ 60	$ 95
4	$ 95	$275	$ 70	$110
5	N.A.	N.A.	$ 80	$125
6	N.A.	N.A.	$ 90	$140
7	N.A.	N.A.	$100	$155
8	N.A.	N.A.	$110	$170

TABLE 3-7

ESTIMATED CONVERSION COSTS FOR BUOYS AND FIXED AIDS

Power Packages Required	# of Buoys		Battery Cost	Zener Diode Cost	Blocking Diode Cost	Solar Array Cost	Aid Conversion Cost	Total
1/2	380	Low Est	36100	1900	-	7600	24700	70300
		High Est	60800	9500	-	57760	76000	204060
1	651	Low Est	61845	3255	-	26040	42315	133455
		High Est	104160	16275	-	197904	130200	448539
2	2091	Low Est	397290	20910	4182	167280	156825	746487
		High Est	669120	104550	20910	1271328	470475	2536383
3	516	Low Est	147060	7740	1548	61920	43860	262128
		High Est	247680	38700	7740	470592	129000	893712
4	126	Low Est	47880	2520	504	20160	11970	83034
		High Est	80640	12600	2520	153216	34650	283626
>4	211	Low Est	80180	4220	844	33760	20045	139049
		High Est	135040	21100	4220	256576	58025	474961
							BUOYS - LOW EST TOTAL	$1434453
							BUOYS - HIGH EST TOTAL	$4841281
	# of Fixed Aids							
1/2	3506	Low Est	333070	17530	-	70120	140240	560960
		High Est	560960	87650	-	532912	227890	1409412
1	2427	Low Est	230565	12135	-	97080	97080	436860
		High Est	388320	60675	-	737808	157755	1344558
2	2633	Low Est	500270	26330	5266	210640	131650	874156
		High Est	842560	131650	26330	1600864	210640	2812044
3	715	Low Est	203775	10725	2145	85800	42900	345345
		High Est	343200	53625	10725	652080	67925	1127555
4	316	Low Est	120080	6320	1264	50560	22120	200344
		High Est	202240	31600	6320	384256	34760	659176
5	194	Low Est	92150	4850	970	38800	15520	152290
		High Est	155200	24250	4850	294880	24250	503430
6	51	Low Est	29070	1530	306	12240	4590	47736
		High Est	48960	7650	1530	93024	7140	158304
7	112	Low Est	74480	3920	784	31360	11200	121744
		High Est	125440	19600	3920	238336	17360	404656
8	11	Low Est	8360	440	88	3520	1210	13618
		High Est	14080	2200	440	26752	1870	45342
>8	67	Low Est	50920	2680	536	21440	7370	82946
		High Est	85760	13400	2680	162944	11390	276174
							FIXED AIDS - LOW EST TOTAL	2835999
							FIXED AIDS - HIGH EST TOTAL	8740651
							TOTAL ESTIMATED CONVERSION COST - LOW	$4270452
							- HIGH	$13581932

of $500 for a suitable reconditioning charger is given. Although the need for such equipment may be unnecessary, it is prudent to include this in the "worst of the worst" situation; therefore, for the high estimate a total of 90 reconditioning chargers (distributed according to need) has been assumed, or $45,000.

3.2 Development of Annual Cost Estimates

Annual differential operating costs compared to the present system must also be considered. The outstanding ones are battery disposal and personnel cost:

3.2.1 Battery Disposal

The cost for the disposal of batteries varies most directly as a function of the number disposed of per year, which in turn varies as a function of the battery's economic life, the failure rate, and the initial installation program. For the purposes of this analysis a 6-year economic life, 20 percent per year failure rate, and 5-year initial installation program will be assumed (the logic of these choices will be more readily apparent after discussion of the economic analysis in Section 5.0). Based on these assumptions and using a 17-year initial cycle, there will be an average of 3,846 100-Ah battery units (consisting of 2 batteries for each 100-Ah battery unit) disposed of per year.

For the low estimate, it is estimated that batteries will yield a return of $3 each, that is, they will be able to be sold. Consultation with industry sources established that although the present scrap battery market is weak to nonexistent, the near future is expected to bring the return of an active market. Indeed, the quality of the components used in the batteries to be used in connection with solar power is high and should command a premium price. The total return under these conditions is estimated to be $23,076 per year.

For the high estimate, cost is less clear and must be inferred. Experience in the First Coast Guard District suggests a cost of about 1.5 percent of battery cost as the cost of disposal for the casing only. Should the electrolyte be neutralized before treating it as sewage, a cost of $1.92 for chemicals plus 0.25 manhours labor appears reasonable for an estimate, or $8.17 per battery.[9] Using the average of 3,846 100-Ah battery units, as previously explained, as the number disposed of per year and the high estimate of $1.60 per Ah for battery cost, a total high estimate of $40,652 is derived.

3.2.2 Personnel

At best, no additional personnel will be required; therefore, a zero cost is used as the low estimate.

For the high estimate, it will be assumed that one E-6 petty officer will be needed as an instructor at Aids to Navigation School and that one GS-7 civilian will be needed as a Battery Disposal Manager. The annual standard personnel salary costs for these personnel are $12,900 and $12,700,

respectively.[10] The annual personnel life cycle costs of $25,800 and $25,400, respectively, are derived by multiplying by a factor of 2.0.[11]

A summary of the total system cost estimates for both project costs and annual costs is shown in Table 3-8.

Two additional items should be mentioned: new facilities and design costs. Consultation with various personnel at the R&D Center and Coast Guard Headquarters indicates that the likelihood of needing any new facilities, compared to the present ones, is extremely remote and are best disregarded in the present analysis. Similarly, since design needs are very low and uncomplicated, associated costs are relatively insignificant and best treated as a part of normal support efforts. These also will be disregarded.

TABLE 3-8

SUMMARY OF TOTAL SYSTEM COST ESTIMATES

Project Costs	Estimated Costs Low	Estimated Costs High
System Conversion	$4270452	$13581932
Initial Inventory	349674	1192228
Training	7100	7100
Reconditioning Charges for Batteries	0	45000
Total Project Cost	$4627226	$14826260
Annual Costs (excluding system failures)		
Battery disposal*	$(23076)	$40652
Personnel		
a. A/N School Instructor	0	25800
b. Battery Disposal Manager	0	25400
	$(23076)	$91852

*Battery disposal cost assumes 5-year conversion program, 6-year economic life, and 20% per year failure rate.

4.0 SYSTEM BENEFIT DEVELOPMENT

4.1 Measurable Benefits

4.1.1 Current Primary Battery Expenditures

Primary battery costs since 1969 are shown in Table 4-1. Consultation with the McGraw-Edison Company, the principal vendor of batteries to the Coast Guard, established that the 20 percent rise in costs between 1974 and 1976 was abnormal and that future costs should not rise at a rate significantly different from "normal" inflation. Of course, to this must be added the caveat that prices from a supplier in a monopoly or near-monopoly position are less affected by market forces and often rise faster than those more affected by competitive pressures.

For both the low and high estimates of benefits from this source, the 1977 figure shown in Table 4-1 will be used ($2,254,350).

4.1.2 Battery Disposal

Since the only identifiable out-of-pocket expenses at the present time come from the First and Fourteenth Coast Guard Districts, their total expense ($27,890) will be used as the low estimate of benefits. Also, since there does not now exist a Battery Disposal Manager, per se, no claim of benefit will be made.

The high estimate is more difficult to establish since there is no trustworthy information available and the impact of the Resource Conservation and Recovery Act of 1976 is unknown. However, there is an inferential process that may be suggestive. Headquarters' records for the battery expenditure account reflect a total expenditure of $1,450,000 for FY76, but Supply Center, Brooklyn, records reflect an expenditure of $2,147,000; thus, there is a statistical discrepancy of about one-third. Applying this to the Headquarters record for the Fourteenth District for FY76, and adding 5 percent to bring the figure in line with 1977 figures, then dividing this figure into the $8,000 recurring battery disposal cost previously mentioned, a figure of 16.4 percent as the battery disposal cost as a percentage of battery cost is obtained. Rounding to 20 percent and doubling, since battery disposal costs appear sure to rise precipitously, a reasonable estimate is obtained for the high benefit estimate, that is, 40 percent of total battery costs. Applying this to the 1977 battery cost estimate, an estimate of $901,740 is derived. Additionally, since a GS-7 civilian Battery Disposal Manager has been claimed previously as a potential high cost component, the annual personnel life cycle cost of such a person ($25,400) can also be claimed as a potential high benefit. This is permitted on the assumption that the disposal of batteries used in the solar energy scheme will not come within the "hazardous waste management" provisions of the Resource Conservation and Recovery Act.

4.1.3 Miscellaneous Benefits

Certain obvious potentially quantifiable benefits can be identified where the present associated costs are impossible to derive, for example:

Decreased underway time for buoy tenders because of lower servicing requirements with attendant savings in fuel. (The actual effects of this are somewhat uncertain but the potential is there, with one estimate received being no more than 50 hours per year for a WLB and that being time with the buoy on deck rather than steaming time.)

Increased use of aids-to-navigation teams in lieu of buoy tenders to render certain servicing requirements to aids; permissible because of the smaller batteries involved with the new system.

Decreased vehicle costs for handling batteries during the disposal process.

To cover items such as these, it is necessary to impute a cost. According to the Commandant (G-CBU), for FY76 the total cost of the short-range aids-to-navigation program was $115,617,000 including support costs (i.e., overhead). For the purposes of this report, the imputed benefit claimed for both the low and high estimates will be one-tenth of one percent of the FY76 official budget figure, or $115,617.

A summary of the estimated benefits is shown in Table 4-2.

4.2 Non-Quantifiable Benefits

Since the imputed figure assumed above for miscellaneous benefits is meant to include any benefit with a tangible value, the principal non-quantifiable benefit is the greatly reduced handling of heavy batteries, both shipboard and on shore, with attendant increases in on-the-job safety, decreased accidents, and decreased fatigue.

Another benefit here will be the decreased inventory and storage problems associated with handling fewer types of batteries.

TABLE 4-1

BATTERY COSTS (1969-1977)

FISCAL YEAR	TOTAL COST
1969	$1,833,000
1970	1,625,000
1971	1,834,000
1972	1,797,000
1973	1,858,000
1974	1,790,000
1975	(not available)
1976	2,147,000
1977	2,254,350 (est)

NOTE: All figures to nearest thousand. Figures for 1969-1974 from Enclosure (3) to Commandant (G-EOE-3/61) memorandum 10504 dated 11 November 1974. Figure for 1976 from Supply Center, Brooklyn (excludes transition quarter). Unable to derive figure for 1975 from Headquarters, Supply Center, or vendor records. Figure for 1977 is the 1976 figure inflated by 5%.

TABLE 4-2

SUMMARY OF ESTIMATED BENEFITS

Item	Estimated Benefit Low	High
Current Primary Battery Expenditures	$2,254,350	$2,254,350
Battery Disposal	27,890	901,740
Battery Disposal Manager	0	25,400
Miscellaneous Benefits	115,617	115,617
Total	$2,397,857	$3,297,107

5.0 ANALYSIS

The applicable precepts for economic analyses are set forth in Office of Management and Budget Circular A-94 dated 27 March 1972, and in the Naval Facilities Engineering Command publication NAVFAC P-442.(12) Accordingly, the discount rate used in the present analysis is 10 percent; also, the discount factors used come from Appendix D, Tables A and B, of NAVFAC P-442.

5.1 Assumptions

In each of the following analyses, the following assumptions are made:

(1) The beginning of any conversion program will start in 5 years.

(2) Aids are converted in a strictly linear sequence beginning with the first day of the year.

(3) Replacements for cause (i.e., system failures) occur only once in a given year and include all failures from any source, including theft, vandalism, defect, destruction, personnel errors, and all other causes.

(4) Replacements for age are accomplished in the same sequence and distribution as the initial conversion program.

(5) All power package components are scrapped at the end of the indicated economic life and replaced in kind.

(6) All benefits accrue at the same rate as the aids are corrected and, in particular, are as follows (where n equals the number of years for the conversion program):

YEAR	FRACTION OF BENEFIT
1	1/2n
2	3/2n
3	5/2n
.	.
.	.
.	.
.	.
n	2n-1/2n
n+1	2n/2n

(7) Project life totals 17 years after the initial 5-year wait for funding and completion of development. This is equal to 3 complete replacement cycles for a 5-year conversion program beginning in FY84.

(8) The initial inventory of power package components, the initial training, and the purchase of reconditioning chargers are all assumed to be expended during the first year of the initial replacement program.

5.2 Examination of the Independent Variables

Given the above assumptions, it is evident that the significant independent variables are economic life, conversion program, and failure rate.

Consultation with various R&D Center and Coast Guard Headquarters personnel combined with independent judgment established the most reasonable combination of the independent variables, in particular, a conversion program of 5 years, an economic life of 6 years, and a failure rate of 20 percent per year. The 6-year economic life was chosen because it corresponds to the nominal relief cycle for buoys.

Using the assumptions previously discussed, the present values of both costs and benefits for both the low and high estimates of each were calculated as shown in Table 5-1. Four benefit-cost (BCR) ratios are derived as follows:

	BENEFIT	COST			RATIO
1.	Low	Low	BCR	= 9346/5534 =	1.69
2.	Low	High	BCR	= 9346/19065 =	0.49
3.	High	Low	BCR	= 12848/5534 =	2.32
4.	High	High	BCR	= 12848/19065 =	0.67

In order to check the sensitivity of the analysis to changes in the failure rate, present values were again calculated but for 10 and 30 percent per year, respectively. These are shown in Table 5-2 and 5-3. By inspection, it can be seen that the effects on the present values, and thus the BCRs, are negligible.

Similarly, the effects of a shorter conversion program need to be examined. Economic life and failure rate were held constant and present values were calculated for a 3-year conversion program as shown in Table 5-4. Obviously, there is a significant effect on the BCRs, which are calculated as follows:

	BENEFIT	COST			RATIO
1.	Low	Low	BCR	= 10510/7655 =	1.37
2.	Low	High	BCR	= 10510/26143 =	0.40
3.	High	Low	BCR	= 14443/7655 =	1.89
4.	High	High	BCR	= 14443/26143 =	0.55

The effect of increasing economic life to 8 years, while holding the conversion program at 5 years and failure rate at 20 percent per year is shown in Table 5-5. Inspection reveals a slight effect on the BCRs, which are calculated as follows:

TABLE 5-1

PRESENT VALUE CALCULATIONS FOR FIVE-YEAR CONVERSION PROGRAM, SIX-YEAR ECONOMIC LIFE, AND TWENTY PER CENT FAILURE RATE

Project Year	Disc. Factor	Assumed Cost Low Est	Assumed Cost High Est	Assumed Benefit Low Est	Assumed Benefit High Est	Present Value-Cost Low Est	Present Value-Cost High Est	Present Value-Benefit Low Est	Present Value-Benefit High Est
6	.592	1279K	4209K	239K	329K	757K	2492K	141K	195K
7	.538	1057	3460	719	989	569	1861	387	532
8	.489	1192	3956	1199	1648	583	1934	586	806
9	.445	1328	4451	1678	2307	591	1981	747	1027
10	.405	1463	4946	2158	2965	593	2003	874	1201
11	.368	676	2476	2398	3296	249	911	882	1213
12	.334	859	3101	2398	3296	287	1036	801	1101
13	.304	896	3226	2398	3296	272	981	729	1002
14	.276	932	3351	2398	3296	257	925	662	910
15	.251	969	3476	2398	3296	243	872	602	827
16	.228	1006	3601	2398	3296	229	821	547	751
17	.208	859	3100	2398	3296	179	645	499	686
18	.189	903	3248	2398	3296	171	614	453	623
19	.172	912	3277	2398	3296	157	564	412	567
20	.156	920	3312	2398	3296	144	517	374	514
21	.142	929	3336	2398	3296	132	474	341	468
22	.129	938	3366	2398	3296	121	434	309	425
				PRESENT VALUE		5534K	19065K	9346K	12848K

Assumptions

Conversion Program: 5 years

Economic Life: 6 years

Replacement Rate: 20%/year

TABLE 5-2

PRESENT VALUE CALCULATIONS FOR FIVE-YEAR CONVERSION PROGRAM, SIX-YEAR ECONOMIC LIFE, AND TEN PER CENT FAILURE RATE

Project Year	Disc. Factor	Assumed Cost Low Est	Assumed Cost High Est	Assumed Benefit Low Est	Assumed Benefit High Est	Present Value-Cost Low Est	Present Value-Cost High Est	Present Value-Benefit Low Est	Present Value-Benefit High Est
6	.592	1244K	4089K	239K	329K	736K	2421K	141K	195K
7	.538	952	3102	719	989	512	1669	387	532
8	.489	1017	3360	1199	1648	497	1643	586	806
9	.445	1083	3617	1678	2307	482	1610	747	1027
10	.405	1148	3874	2158	2965	465	1569	874	1201
11	.368	327	1286	2398	3296	120	473	882	1213
12	.334	768	2791	2398	3296	256	932	801	1101
13	.304	875	3157	2398	3296	266	960	729	1002
14	.276	982	3523	2398	3296	271	972	662	910
15	.251	1089	3889	2398	3296	273	976	602	827
16	.228	1195	4250	2398	3296	272	969	547	751
17	.208	861	3111	2398	3296	179	647	499	686
18	.189	1086	3878	2398	3296	205	733	453	623
19	.172	1123	4005	2398	3296	193	689	412	567
20	.156	1160	4132	2398	3296	181	645	374	514
21	.142	1197	4259	2398	3296	170	605	341	468
22	.129	1234	4382	2398	3296	159	565	309	425
				PRESENT VALUE		5237K	18078K	9346K	12848K

Assumptions

Conversion Program: 5 years
Economic Life: 6 years
Replacement Rate: 10%/year

TABLE 5-3

PRESENT VALUE CALCULATIONS FOR FIVE-YEAR CONVERSION PROGRAM, SIX-YEAR ECONOMIC LIFE, AND THIRTY PER CENT FAILURE RATE

Project Year	Disc. Factor	Assumed Cost Low Est	Assumed Cost High Est	Assumed Benefit Low Est	Assumed Benefit High Est	Present Value-Cost Low Est	Present Value-Cost High Est	Present Value-Benefit Low Est	Present Value-Benefit High Est
6	.592	1314K	4292K	239K	329K	778K	2541K	141K	195K
7	.538	1162	3818	719	989	625	2054	387	532
8	.489	1367	4553	1199	1648	668	2226	586	806
9	.445	1573	5287	1678	2307	700	2353	747	1027
10	.405	1637	5542	2158	2965	663	2245	874	1201
11	.368	676	2476	2398	3296	249	911	882	1213
12	.334	758	2744	2398	3296	253	916	801	1101
13	.304	783	2828	2398	3296	238	860	729	1002
14	.276	808	2912	2398	3296	223	804	662	910
15	.251	833	2996	2398	3296	209	752	602	827
16	.228	840	3018	2398	3296	192	688	547	751
17	.208	758	2750	2398	3296	158	572	499	686
18	.189	766	2777	2398	3296	145	525	453	623
19	.172	769	2787	2398	3296	132	479	412	567
20	.156	772	2797	2398	3296	120	436	374	514
21	.142	775	2807	2398	3296	110	399	341	468
22	.129	776	2809	2398	3296	100	362	309	425
				PRESENT VALUE		5563K	19123K	9346K	12848K

Assumptions

Conversion Program: 5 years
Economic Life: 6 years
Replacement Rate: 30%/year

TABLE 5-4

PRESENT VALUE CALCULATIONS FOR THREE-YEAR CONVERSION PROGRAM, SIX-YEAR ECONOMIC LIFE, AND TWENTY PER CENT FAILURE RATE

		Assumed Cost		Assumed Benefit		Present Value-Cost		Present Value-Benefit	
Project Year	Disc. Factor	Low Est	High Est	Low Est	High Est	Low Est	High Est	Low Est	High Est
6	.592	1894K	6183K	400K	549K	1121K	3660K	237K	325K
7	.538	1762	5764	1200	1647	948	3101	646	886
8	.489	1987	6589	2000	2747	972	3222	978	1343
9	.445	676	2476	2398	3296	301	1102	1067	1467
10	.405	909	3271	2398	3296	368	1325	971	1335
11	.368	1143	4065	2398	3296	421	1496	882	1213
12	.334	1446	5096	2398	3296	483	1702	801	1101
13	.304	1507	5304	2398	3296	458	1612	729	1002
14	.276	1568	5928	2398	3296	433	1636	662	910
15	.251	1326	4689	2398	3296	333	1177	602	827
16	.228	1387	4897	2398	3296	316	1117	547	751
17	.208	1448	5105	2398	3296	301	1062	499	686
18	.189	1520	5358	2398	3296	287	1013	453	623
19	.172	1536	5412	2398	3296	264	931	412	567
20	.156	1552	5466	2398	3296	242	853	374	514
21	.142	1496	5267	2398	3296	212	748	341	468
22	.129	1512	5321	2398	3296	195	686	309	425
				PRESENT VALUE		7655K	26143K	10510K	14443K

Assumptions

Conversion Program: 3 years
Economic Life: 6 years
Replacement Rate: 20%/year

TABLE 5-5

PRESENT VALUE CALCULATIONS FOR FIVE-YEAR CONVERSION PROGRAM, EIGHT-YEAR ECONOMIC LIFE, AND TWENTY PER CENT FAILURE RATE

		Assumed Cost		Assumed Benefit		Present Value-Cost		Present Value-Benefit	
Project Year	Disc. Factor	Low Est	High Est	Low Est	High Est	Low Est	High Est	Low Est	High Est
6	.592	1279K	4173K	239K	329K	757K	2470K	141K	195K
7	.538	1057	3460	719	989	567	1861	387	532
8	.489	1192	3956	1199	1648	583	1934	586	806
9	.445	1328	4421	1678	2307	591	1967	747	1027
10	.405	1463	4916	2158	2965	593	1991	874	1201
11	.368	676	2476	2398	3296	249	911	882	1213
12	.334	676	2476	2398	3296	226	827	801	1101
13	.304	676	2476	2398	3296	206	753	729	1002
14	.276	793	2873	2398	3296	219	793	662	910
15	.251	817	2953	2398	3296	205	741	602	827
16	.228	841	3033	2398	3296	192	692	547	751
17	.208	865	3113	2398	3296	180	648	499	686
18	.189	889	3193	2398	3296	168	603	453	623
19	.172	793	2877	2398	3296	136	495	412	567
20	.156	793	2877	2398	3296	124	449	374	514
21	.142	793	2877	2398	3296	113	409	341	468
22	.129	811	2937	2398	3296	105	379	309	425
				PRESENT VALUE		5214K	17903K	9346K	12848K

Assumptions

Conversion Program: 5 years
Economic Life: 8 years
Replacement Rate: 20%/year

	BENEFIT	COST			RATIO
1.	Low	Low	BCR	= 9346/5214	= 1.79
2.	Low	High	BCR	= 9346/17903	= 0.52
3.	High	Low	BCR	= 12848/5214	= 2.46
4.	High	High	BCR	= 12848/17903	= 0.72

As can be seen, the longer economic life serves to enhance the BCRs.

Examination of the three significant independent variables reveals that change in the failure rate does not materially affect the managerial information from the analysis, nor do changes in the economic life; however, the length of time scheduled for the conversion program substantially affects the outcome.

5.3 Presentation of the Benefit-Cost Ratios

What is needed at this point is a "tool" to help the reader develop a "feel" for the meaning of the various BCRs. This is provided by Figure 5-1. Here, two different quadilaterals have been formed by plotting the benefit-cost ratios against project cost. These quadrilaterals represent (i.e., trace) what can be termed an approximate "solution space" for BCRs versus project cost, that is, the approximate set (in the mathematical sense) of BCRs from the "best of the best" situation to the "worst of the worst" situation for 3- and 5-year conversion programs.

This approach offers the advantage of permitting the approximation of BCRs associated with assumptions other than those set forth in this report. For example, what if a reader is convinced that the project will cost about $10,000,000 and be phased in over 4 years? Interpolation midway between the two low benefit lines and between the two high benefit lines at $10,000,000 on the abscissa establishes an approximate range of 0.98 to 1.35 for the associated BCRs. The reader then must be satisfied as to the level of benefits before a specific BCR can be estimated. As another example, suppose a reader is convinced that the solar cells will cost $10 per watt and the battery disposal cost will run about 20 percent of battery cost with the conversion program assumed to be 5 years. From Table 3-4, the total number of watts for the system (187,664) is multiplied by the difference between the low estimate (i.e., $5 per watt) used in this report and the new figure ($10). This gives $938,320 which is added to the total, low estimate system cost from Table 3-7 ($4,270,452) to arrive at a new estimated project cost of $5,208,772. Locating this number on the abscissa of Figure 5-1 and reading at the low and high benefit lines gives an approximate BCR range of 1.65 to 2.26. Since the high benefit shown in Table 4-2 ($3,297,107) is being reduced by some 13.7 percent (20% x $2,254,350), the reader can interpolate graphically (or mathematically) and arrive at an estimated BCR of 2.18. Exercises of this sort permit a reader to approximate the BCR associated with the reader's set of assumptions.

Figure 5-1 is the core of the present analysis. It permits an approximation of the applicable BCR depending upon the reader's belief in the assumptions used. It affords numerous considerations that can be used in the decision-making process. Finally, since the centroids of the quadrilaterals

lie above the "BCR = 1.0" line, this suggests very strongly that the benefits associated with converting the present primary battery system to one relying upon solar energy should clearly outweigh the costs. With the true future state of affairs involving benefits and costs being unknown, as is the case here, the centroid provides a reasonable approximation of the actual BCR.

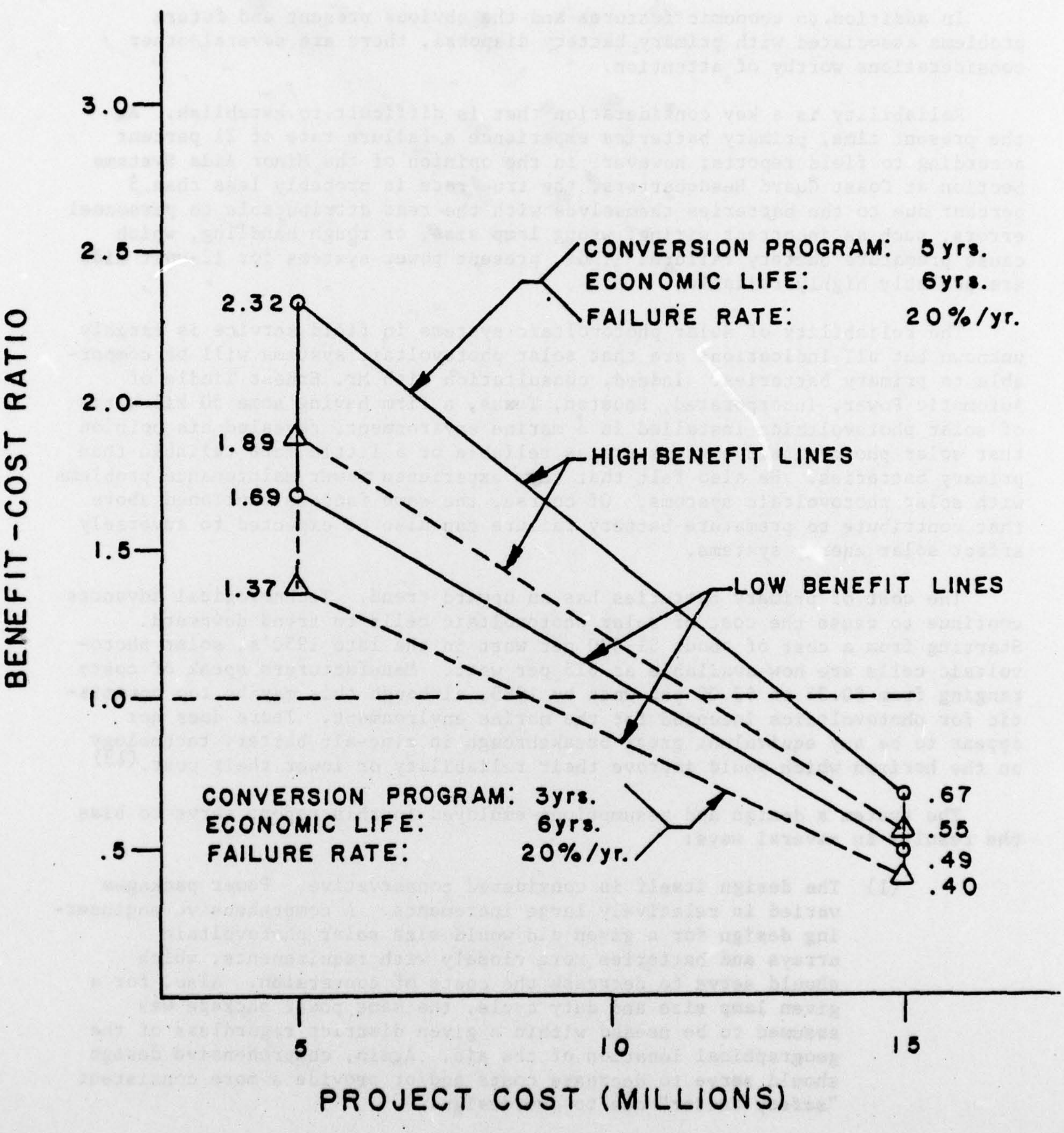

FIGURE 5-1

PROJECT COST VERSUS BENEFIT-COST RATIO

6.0 OTHER CONSIDERATIONS

In addition to economic features and the obvious present and future problems associated with primary battery disposal, there are several other considerations worthy of attention.

Reliability is a key consideration that is difficult to establish. At the present time, primary batteries experience a failure rate of 21 percent according to field reports; however, in the opinion of the Minor Aids Systems Section at Coast Guard Headquarters, the true rate is probably less than 5 percent due to the batteries themselves with the rest attributable to personnel errors, such as incorrect wiring, wrong lamp size, or rough handling, which cause premature battery failure. Thus, present power systems for 12-volt aids are probably highly reliable.

The reliability of solar photovoltaic systems in field service is largely unknown but all indications are that solar photovoltaic systems will be comparable to primary batteries. Indeed, consultation with Mr. Ernest Tindle of Automatic Power, Incorporated, Houston, Texas, a firm having some 50 kilowatts of solar photovoltaics installed in a marine environment, revealed his opinion that solar photovoltaic systems are as reliable or a little more reliable than primary batteries. He also felt that they experience fewer maintenance problems with solar photovoltaic systems. Of course, the same factors mentioned above that contribute to premature battery failure can also be expected to adversely affect solar energy systems.

The cost of primary batteries has an upward trend. Technological advances continue to cause the cost of solar photovoltaic cells to trend downward. Starting from a cost of about $1,000 per watt in the late 1950's, solar photovoltaic cells are now available at $15 per watt. Manufacturers speak of costs ranging from $0.35 to $2.00 per watt by 1985, although this may be too optimistic for photovoltaics intended for the marine environment. There does not appear to be any equivalent great breakthrough in zinc-air battery technology on the horizon which would improve their reliability or lower their cost.[13]

The system's design and assumptions employed in this report serve to bias the results in several ways:

(1) The design itself is considered conservative. Power packages varied in relatively large increments. A comprehensive engineering design for a given aid would size solar photovoltaic arrays and batteries more closely with requirements, which should serve to decrease the costs of conversion. Also, for a given lamp size and duty cycle, the same power package was assumed to be needed within a given district regardless of the geographical location of the aid. Again, comprehensive design should serve to decrease costs and/or provide a more consistent "safety factor" due to overdesign.

(2) Solar photovoltaic arrays and batteries may in fact last longer than the 6-year life assumed, particularly the solar photovoltaic arrays; thus, a benefit may accure. Also, the array and batteries may have a terminal value, another benefit.

(3) Not all of the 3.5 feet diameter buoys have the buoyant and stability characteristics needed for fitting with solar photovoltaic arrays. There are about 417 of these buoys, but they were included in the overall count since their distribution by lamp rating and duty cycle was not known. Many of the 5 feet diameter buoys are similarly questionable. There are about 612 of them, but they were also included for the same reason as before. These effects are offset somewhat by the current program for replacing buoys with fixed structures, since all structures can be fitted with solar photovoltaics, and by the technologic trend of increasing the maximum power per unit weight and area of photovoltaics, which may allow fitting solar photovoltaic arrays on smaller buoys in the future.

The potential for theft once solar photovoltaic arrays are installed appears to be great since there are so many ordinary applications for solar photovoltaics. This potential may be reduced by indelibly marking the array "U.S. Property, U.S. Coast Guard" and by choice of attachment to the aid. The potential cost is unknown.

Some miscellaneous comments/questions that have not been considered in this report are: (a) Will enlisted rate substitution be required if a shift is made to solar photovoltaics? (b) Will the present high turnover rate for personnel in aids to navigation assignments tend to exacerbate problems if the change is made? (c) Does the Coast Guard wish to continue having but one supplier of batteries? Questions such as these should also be addressed before planning a conversion.

7.0 CONCLUSION

The import of this report is clear: converting 12-volt lighted aids to navigation from reliance on primary air-cell batteries to reliance on solar photovoltaics is attractive from an economic point of view. Thus, the decision to convert should be made on technical considerations, not economic ones. Technological advances, with attendant reductions in the cost of supplying solar photovoltaic energy, combined with environmental protection considerations provide powerful arguments in favor of planning conversion to solar photovoltaics.

REFERENCES

(1) Ryba, J.S., and Naus, D.A., "Laboratory Evaluation of Solar Power Units for Marine Aids to Navigation" (Report No. CG-D-106-76). Springfield, Virginia: National Technical Information Service (NTIS), 1976.

(2) Commandant Instruction 10500.33A of July 1973 provides standard procedures for disposal and lists permissible alternatives in order of preference.

(3) Commandant (G-WAN-1) memorandum 7300/16500 dated 21 November 1977.

(4) Proposal to Develop Computer Programs for Design and Performance Analysis of Navigation-Aid Power Systems (JPL Proposal 51-384, 3 September 1974). Pasadena, California: Jet Propulsion Laboratory, California Institute of Technology, 1974.

(5) Ryba and Naus, op. cit., p. 62.

(6) Climatic Atlas of The United States, U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service, June 1968, p. 70.

(7) The Nautical Almanac For The Year 1974. Washington, DC: U.S. Government Printing Office, 1972.

(8) "Survey of Secondary Batteries for Application in U.S. Coast Guard Aids to Navigation (Buoys)," Final Report (WQEC/C 76-296). Crane, Indiana: Naval Weapons Support Center, July 1976, pp. 18-19.

(9) Ibid, p. 18.

(10) Commandant Notice 7100 of 26 April 1977.

(11) Planning and Programming Manual (CG-411), Amendment No. 11.

(12) Brown, R.S., and Shachmut, K.M., Economic Analysis Handbook (NAVFAC P-442). Springfield, Virginia: NTIS, 1975.

(13) Enclosure (1) to Commandant (G-EOE-3/61) memorandum 10504 dated 11 November 1974.